Accepted: 6 November 2018
DOI: 10.1002/ajim.22925

RESEARCH ARTICLE

WILEY AMERICAN JOURNAL OF INDUSTRIAL MEDICINE

# Persistent self-reported ear and hearing problems among World Trade Center-exposed firefighters and emergency medical service workers, 2001-2017—A longitudinal cohort analysis

Hilary L. Colbeth MPH[1,2] | Rachel Zeig-Owens DrPH, MPH[1,2,3] | Yang Liu MS[1,2] | Mayris P. Webber DrPH, MPH[1,3,4] | Theresa M. Schwartz MS[1,2] | Charles B. Hall PhD[3] | David J. Prezant MD[1,5]

[1] Fire Department of the City of New York, Bureau of Health Services, Brooklyn, New York

[2] Pulmonology Division, Department of Medicine, Montefiore Medical Center, Bronx, New York

[3] Department of Epidemiology and Population Health, Albert Einstein College of Medicine, Bronx, New York

[4] Department of Epidemiology and Population Health, Montefiore Medical Center, Bronx, New York

[5] Pulmonology Division, Department of Medicine, Albert Einstein College of Medicine, Bronx, New York

Correspondence
Rachel Zeig-Owens, DrPH, MPH, FDNY Headquarters, 9 Metrotech Center, 8N7, Brooklyn, NY 11201.
Email: rachel.zeig-owens@fdny.nyc.gov

**Funding information**
National Institute for Occupational Safety and Health (NIOSH), Grant numbers: 200-2011-39378, 200-2011-39383, 200-2017-93326, 200-2017-93426

**Background:** The goal of this study was to estimate the impact of exposure to the World Trade Center (WTC) site on annual and persistent rates of otalgia and hearing impairment among Fire Department of the City of New York (FDNY) Firefighters and Emergency Medical Service Workers (EMS).

**Methods:** Responders completed routine physical health questionnaires at monitoring visits. We used logistic and marginal logistic regression models to explore the association between otalgia and hearing impairment and WTC arrival time.

**Results:** The highest-exposed group had greater odds of persistent ear symptoms (OR 1.33, 95%CI 1.11-1.59) compared with the least-exposed; the odds of persistent hearing problems between the groups were not significantly different. We found consistent WTC-exposure gradients when the average population odds of these outcomes were assessed each year.

**Conclusions:** Our findings demonstrate that the odds of long-term ear symptoms were significantly associated with the intensity of WTC exposure.

KEYWORDS
hearing, prevalence, rescue/recovery workers, self-report, world trade center

## 1 | INTRODUCTION

Occupational hearing loss is one of the most common work-related conditions in the United States, with about 22 million adults exposed to hazardous noise levels at work and over 30 million exposed to chemicals harmful to the ear and hearing.[1] In the 2014 National Health Interview Survey (NHIS), 14.8% of men reported loud, brief noise exposure as a cause of hearing loss and 35.6% cited long-term noise exposure as a contributor.[2] These issues may be relevant for rescue/recovery workers who were exposed to the collapse and burning of the World Trade Center (WTC) towers. Recent associations have been found between exposure to the WTC disaster and reporting of moderate and persistent hearing problems or loss.[3,4]

Institution at which the work was performed: Fire Department of the City of New York.

Although the exact timestamps for arrival to work at the WTC are unavailable, FDNY responders who were present for the collapses of the South and North towers, between 9:59 AM and 10:28 AM on September 11, 2001 (9/11), were likely exposed to the greatest acute noise. The environment of the WTC collapses and relief operations involved sirens, falling debris, searching for remains, shoring timbers, air-hammers, gasoline-powered saws, and at least three heavy-lift cranes operating continuously.[5] Personal protective equipment such as half- and full-face respirators was used rarely on 9/11, and intermittently after 9/11,[6,7] and therefore did not provide much protection.

Dust and smoke from the disaster were characterized by the presence of lead, benzene, calcium carbonate, silicate, sulfate, asbestos, fibrous glass, polycyclic aromatic hydrocarbons, naphthalene, PCBs, and powdered concrete.[8] Smoke contains harmful chemicals such as benzene and combustion products including lead.[8] Epidemiological studies of lead-exposed workers suggest heavy metals are a risk factor for hearing loss[9] and animal experiments have repeatedly pointed to the cochleotoxic effects of chronic exposure to benzene and other aromatic solvents, which target the cochlear hair cells and cause irreversible hearing impairment.[10,11] Due to the noise and chemical exposures present at the WTC site, in addition to possible rescue/recovery related risk factors for hearing loss including ruptured ear drums or head trauma, we undertook this study to examine the possible link between audiological symptoms and a WTC-exposure effect among Fire Department of the City of New York (FDNY) firefighters and emergency medical service workers (EMS).

In this report, covering the period from 9/11 through December 31, 2017, we use serial, cross-sectional analyses to estimate annual rates of otalgia and hearing impairment among FDNY-WTC-exposed members. Second, we use longitudinal cohort analyses to explore a possible association between level of WTC exposure and persistent rates of otalgia and hearing impairment.

## 2 | MATERIALS AND METHODS

### 2.1 | Study population

Participants eligible for analysis were active (ie, not retired) FDNY firefighters or EMS as of 9/11 who consented to research, completed a physical health questionnaire, had at least one post-9/11 monitoring exam, and arrived at the WTC disaster site between the morning of 9/11 and September 24, 2001 ($N$ = 12 005). We excluded data from 112 workers whose only monitoring exams took place between 2002 and 2005 as we did not ask 12-month ear or hearing questions during this period. The final population included 11 893 men and women. The Montefiore Medical Center/Albert Einstein College of Medicine's Institutional Review Board approved this study.

### 2.2 | Predictor: WTC-exposure

We used information from the earliest self-administered questionnaires conducted during routine FDNY-WTC Health Program (WTCHP) visits to assess WTC exposure based on arrival time. Exposure was categorized based on the FDNY-WTC exposure intensity index[6] as being high (arrived during the morning of 9/11), moderate (arrived afternoon of 9/11 or on 9/12/2001), or low (arrived between 9/13/2001 and 9/24/2001).[12–15]

### 2.3 | Outcomes

We describe self-reported auditory system functioning through two outcome measures, ear symptoms and hearing problems. For every year interval post-9/11 through 2017, we categorized participants as having ear symptoms if they answered affirmatively to questions which inquired about any experience of ear congestion, pain, and/or ringing in the past 12 months on any of their exams within that interval. Similarly, for every 1 year post-9/11, hearing problems were identified if the participant answered affirmatively to questions which asked about any experiences of decreased hearing, hearing aid used (or recommended), and difficulty hearing in the past 12 months on their exams within that interval. Subsequently, we identified persistent ear symptoms and hearing problems among a subset of the population with ≥2 questionnaires ($N$ = 11 476), defining persistence as positive reports of the outcome on all questionnaires after the initial indication.

### 2.4 | Statistical analysis

The annual prevalence of ear symptoms and hearing problems was calculated among the population of those who came in for monitoring exams during that time interval, and separately among men aged 40-69 at the time of the questionnaire. To examine the association between WTC-related exposure and each outcome, we estimated odds ratios (95% CI) from simple and multivariable logistic regression models. Loss to follow-up was assessed by comparing the characteristics of participants who had an exam in the last two 9/11 years of the study (September 12, 2016 to December 31, 2017) to those who did not. All models included WTC exposure with the low-exposure group as the reference population and analyzed ear symptoms and hearing symptoms separately. Both multivariable models of persistent ear symptoms and hearing problems controlled for work assignment on 9/11 (firefighter, EMS), gender, race (white, other), smoking history (never, former, current) and age on 9/11 centered at 40 years—the population mean. A linear trend in the exposure-response relationship was tested by modeling WTC exposure as an ordinal predictor (coded 0 for the low-exposure group, 1 for the moderate-exposure group, and 2 for the high-exposure group). We also ran analyses under a generalized estimating equation (GEE) approach, using marginal logistic regression controlling for centered age and years since 9/11 to estimate the average population effect of predictors over time. The models used an autoregressive within-person correlation structure due to autocorrelation across time; an exchangeable matrix was also considered, but did not fit the data as well.

Sensitivity analyses evaluated the robustness of the observed associations. To ensure that persistent ear and hearing issues were not an artifact of aging, we restricted the population to rescue/recovery workers who were younger than 50 on 9/11 ($N$ = 10 472) and included

the following model predictors: work assignment on 9/11, gender, race, smoking history, and centered age. All analyses were performed using SAS, version 9.4 (SAS Institute, Cary, NC).

## 3 | RESULTS

### 3.1 | Characteristics of the study sample

The study population of 11 893 rescue/recovery participants is described in Table 1. Among the total population, 17.5% ($N = 2080$) of rescue/recovery workers were categorized as highly-exposed, 67.8% ($N = 8,057$) were moderately-exposed, and 14.8% ($N = 1756$) experienced low levels of exposure. On average, participants completed 9 post-9/11 exams over the 16 years of follow-up. Those with 9 or more exams ($N = 7406$) were similar to those with shorter follow-up ($N = 4487$) across gender, race, work assignment on 9/11, and average age on 9/11. Correspondingly, those without exams in the last 2 years of follow-up were demographically comparable to the 74.4% of the population with exams in those years (data not shown). Serial cross-sectional analyses provided annual prevalence measures of ear symptoms (range 19.5-33.0%) and hearing problems (range 11.9-23.6%) which were highest during the last year of follow-up, as anticipated, due to aging. Annual prevalence was consistently higher among men aged 40-69 years compared with rates in the full cohort until the last years of follow-up (Figure 1).

Of the subpopulation with ≥2 exams, the overall prevalence of persistent ear symptoms and hearing problems was 15.9% ($N = 1829$) and 9.5% ($N = 1086$), respectively; 4.8% ($N = 556$) of the population reported both outcomes. Among those with persistent ear symptoms and hearing problems, a large majority were, respectively, white (89.8%; 91.2%), male (96.2%; 96.8%), firefighters (87.0%; 89.1%), and most were moderately-exposed (67.6%; 67.6%), consistent with the characteristics of this cohort. Additionally, those persistently reporting ear symptoms and hearing problems took an average of eight exams. Among those with persistent ear symptoms (answer choices were not mutually exclusive), 81.0% ever experienced ringing in the ears, 69.5% ever reported congestion, and 52.2% ear pain. Not included in the multivariable models was a small subgroup of seven workers who reported WTC-related head trauma. Of this group, 2 reported both persistent ear symptoms and hearing problems, 1 reported only persistent ear symptoms and 1 reported only persistent hearing problems.

**TABLE 1** Population characteristics of the Fire Department of the City of New York rescue/recovery workers

| | Full population ($n = 11\,893$) $N$ (%) |
|---|---|
| Exposure level | |
| High | 2080 (17.5) |
| Moderate | 8057 (67.8) |
| Low | 1756 (14.8) |
| Age on 9/11, y | |
| Mean | 39.7 |
| Range | 19.0-69.6 |
| Work assignment on 9/11 | |
| Fire | 10 148 (85.3) |
| EMS | 1745 (14.7) |
| Gender | |
| Male | 11 544 (97.1) |
| Female | 349 (2.9) |
| Race | |
| Non-Hispanic White | 10 460 (88.0) |
| Other | 1433 (12.0) |
| Smoking history (as of last exam) | |
| Never | 7841 (65.9) |
| Former | 3257 (27.4) |
| Current | 795 (6.7) |
| Retired as of December 31, 2017 | |
| Yes | 7635 (64.2) |
| No | 4258 (35.8) |

9/11, September 11, 2001; EMS, Emergency Medical Services worker.

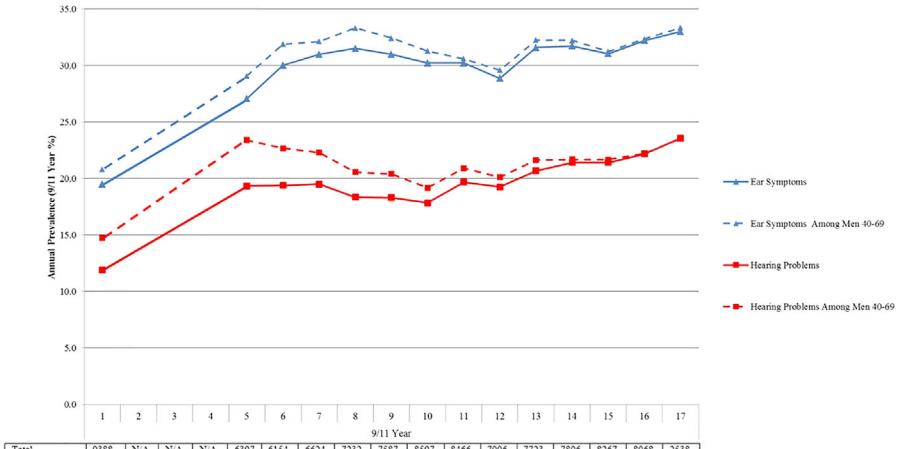
### 3.2 | Associations of 9/11-related exposures with ear symptoms and hearing problems

In our multivariable models, the most highly-exposed group had a greater odds of persistent ear symptoms (odds ratio [OR] 1.33, 95% CI 1.11-1.59). However, the slight increase in hearing problems (OR 1.18, 95% CI 0.93-1.47) (Table 2), was not statistically significant. Modeling exposure continuously, the odds of reporting persistent ear symptoms increased by 16% with higher levels of exposure ($P$ test for trend $P < 0.0001$). Results for persistent hearing problems under both exposure modeling techniques were not statistically significant. Our marginal logistic regression models measuring the average population odds of reporting the outcome in each year, illustrate a consistent WTC-exposure gradient over time for both ear symptoms (Figure 2A) and hearing problems (Figure 2B).

In sensitivity analyses, which restricted to workers younger than 50 on 9/11, the results remained similar to those from the full cohort with the most highly-exposed having higher odds ratios as compared to the lowest-exposed: for persistent ear symptoms (OR 1.30, 95% CI 1.07-1.58) and hearing problems (OR 1.19, 95% CI 0.93-1.52). The overall prevalence of persistent ear symptoms and hearing problems declined slightly, 15.5% and 9.2%, respectively.

## 4 | DISCUSSION

Our serial cross-sectional models illustrate consistent WTC exposure gradients over time for the odds of reporting ear symptoms and hearing problems. In addition, our cohort analyses demonstrate that the intensity of WTC exposure was significantly associated with persistent ear symptoms. This pattern remained in trend and sensitivity analyses restricted to younger responders.




| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Total Questionnaires | 9388 | N/A | N/A | N/A | 6397 | 6154 | 6624 | 7232 | 7587 | 8597 | 8466 | 7906 | 7723 | 7896 | 8267 | 8068 | 2538 |
| Total Questionnaires Among Men 40-69 | 4501 | N/A | N/A | N/A | 3996 | 4065 | 4839 | 5680 | 6254 | 7260 | 7395 | 7016 | 6996 | 7173 | 7538 | 7349 | 2275 |

*Note*: Data was excluded from 9/11 Years 2-4 because no 12-month ear or hearing questions were asked during this period.

**FIGURE 1** Trends in annual prevalence post-9/11 (9/11 years) of ear symptoms and hearing problems. Data were excluded from 9/11 years 2-4 because no 12-month ear or hearing questions were asked during this period. 9/11, September 11, 2001 [Color figure can be viewed at wileyonlinelibrary.com]

These results are important because noise-induced damage to the cochlea may result in vestibular dysfunction and dizziness.[16] In addition, temporary and permanent threshold shifts of hearing acuity have been found to accelerate age-related hearing loss.[17] Although noise level measures were not available during the actual WTC collapse and cleanup periods, we postulate that the experiences of rescue/recovery workers on the pile were probably similar to those of construction workers, who consistently endure above the recommended standard limit of 85 A-weighted decibels (dBA) during a full-shift,[18] an exposure that may cause hearing impairment and noise-induced hearing loss (NIHL).[19]

Despite possible recovery of auditory pure tone thresholds over time, serious damage such as synaptopathy can occur, whereby connections between the inner hair cells and their afferent neurons are progressively lost due to acute noise-induced cochlear trauma.[16,20,21] Synaptopathic mechanisms have been shown to be involved with NHIL[16,22]—a condition longitudinal studies have associated with increases in cardiovascular disease risk factors[23] and declines in

**TABLE 2** Odds ratios for association between 9/11 exposure group of World Trade Center FDNY rescue/recovery workers and persistent Ear Symptoms and Hearing Problems, 2001–2017

| | Population ≥2 questionnaires (*N* = 11 476) | | | |
|---|---|---|---|---|
| | Persistent ear symptoms (*N* = 1829) | | Persistent hearing problems (*N* = 1086) | |
| | Crude OR (95%CI) | Adjusted OR (95%CI)[a] | Crude OR (95%CI) | Adjusted OR (95%CI)[a] |
| Model 1: WTC exposure as categorical variable | | | | |
| High-exposure | 1.32 (1.11-1.58) | 1.33 (1.11-1.59) | 1.17 (0.93-1.46) | 1.18 (0.93-1.47) |
| Moderate-exposure | 1.14 (0.98-1.32) | 1.12 (0.96-1.31) | 1.06 (0.88-1.28) | 1.03 (0.85-1.25) |
| Low-exposure | Reference | Reference | Reference | Reference |
| Model 2: WTC exposure continuous variable | | | | |
| Exposure group (earliest arrival group being highest exposed) | 1.15 (1.05-1.26) | 1.16 (1.06-1.27) | 1.08 (0.97-1.21) | 1.09 (0.97-1.22) |
| Sensitivity analysis: Model restricted to participants <50 years old on 9/11 (*N* = 10 472) | | | | |
| High-exposure | 1.30 (1.07-1.58) | 1.30 (1.07-1.58) | 1.21 (0.95-1.54) | 1.19 (0.93-1.52) |
| Moderate-exposure | 1.15 (0.98-1.36) | 1.14 (0.96-1.34) | 1.16 (0.95-1.42) | 1.10 (0.90-1.36) |
| Low-exposure | Reference | Reference | Reference | Reference |

9/11, September 11, 2001; WTC, World Trade Center; FDNY, Fire Department of the City of New York; EMS, Emergency Medical Services worker; OR, odds ratio; 95% CI, 95% confidence interval.

[a]Exposure measurements adjusted for work assignment on 9/11 (firefighter, EMS), gender, race (white, non-white), smoking history (current, former, non-smoking), and age centered at 40.

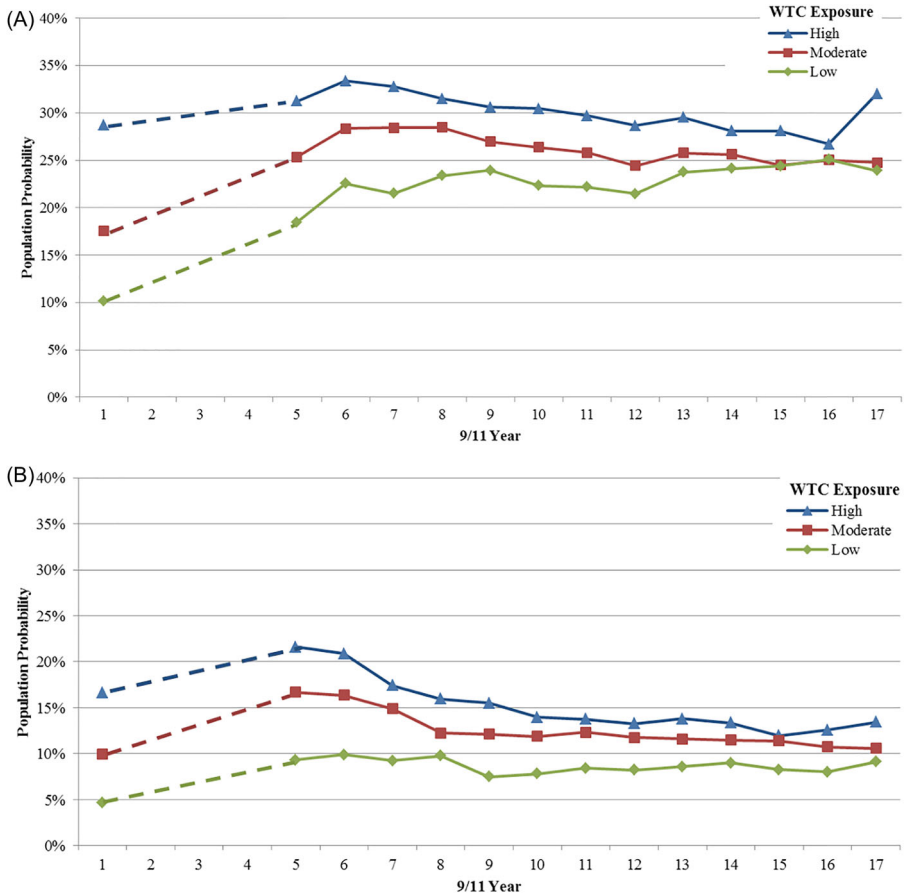



**FIGURE 2** A, Average population probability of Ear Symptoms for a 40-year-old rescue/recovery worker within each 9/11 year by exposure level. B, Average population probability of Hearing Problems for a 40-year-old rescue/recovery worker within each 9/11 year by exposure level. Data were excluded from 9/11 years 2-4 because no 12-month ear or hearing questions were asked during this period. 9/11, September 11, 2001 [Color figure can be viewed at wileyonlinelibrary.com]

cognition, memory, and attention.[24] Given the significant persistence of ear symptoms and that over 80% with the outcome specifically experienced ringing in the ears (tinnitus), these direct and indirect effects on the auditory system may have resulted from the WTC disaster and warrant strategies for evaluation and treatment. Furthermore, studies have shown an association between tinnitus and common comorbidities such as anxiety, depression, short sleep duration, and missing work days.[25] The WTCHP already works to address these disorders, but attention to associated ear issues may alleviate their expression or severity, especially among highly-exposed rescue/recovery workers.

Supportive evidence for our findings has previously been reported by rescue/recovery workers who participate in the World Trade Center Health Registry.[4] We built upon their work by using a more stringent definition of persistence, requiring that symptoms be reported on all surveys after their original report, which, on average, incorporated data from 8 years (1 survey from each year). In contrast, the Registry definition required symptoms reported at two time points. Nonetheless, our prevalence of persistent hearing problems (9.5%) was double the 4.4% among rescue/recovery workers reported by the Registry, which is consistent with the very high WTC exposure levels experienced by the FDNY population. Serial cross-sectional models show a WTC exposure gradient across time for the prevalence of self-reporting hearing problems; however, the cohort models of persistent hearing problems did not find significant associations, which the Registry reported for the most exposed participants (those unable to hear in the dust cloud) using a less stringent definition of persistence.

We grouped auditory issues into separate categories of discomfort within the physical ear and hearing itself. Our outcome of ear symptoms which included pain, ringing, and congestion, captured noise-induced hearing loss caused by extremely loud bursts of sound that strongly impact inner ear structures by damaging sensory tissue and possibly causing tinnitus.[26] Although symptoms may subside, our measure of hearing problems which included decreased hearing, hearing aid use (or recommended use) and difficulty hearing, describes the progressive degeneration of sensory tissue that can occur over time.[26]

Our study has both strengths and limitations. The first limitation is that is unclear whether our outcome measures reflect clinical hearing loss; further research into FDNY audiological data may elucidate this uncertainty. Second, our study was not able to estimate or control for historical occupational or leisure noise level or baseline hearing status.

However, because our occupational cohort of responders was healthy at the time of the WTC disaster, hearing probably was not a significant issue prior to 9/11. Third, although our findings rely on reporting by those who have had at least one post-9/11 monitoring exam, the potential for selection bias and longitudinal dropout may have been mitigated by our cohort's high retention—over 60% of participants completed 9 or more post-9/11 exams and a large majority had an exam within the last 2 years of the study. Those with shorter follow-up were similar to the full population suggesting loss to follow-up was missing at random. Moreover, our rigorous definition of persistence strengthens our conclusions and may deepen our understanding of the effects of the WTC disaster, a valuable tool in the advancement of WTC-member services and treatment. Among the total population, annual prevalence of ear symptoms and hearing problems between the first and fifth years post-9/11 increased from 19.5% to 27.1% and from 11.9% to 19.3%, respectively, with the prevalence among men aged 40-60 increasing similarly. We are unable to pinpoint a root source of that change; however, it may be attributed to a slight difference in question phrasing, aging, or a possible delayed effect of 9/11.

In conclusion, after 16 years of follow-up, earlier WTC arrival time was associated with persistent ear symptoms and, in our serial cross-sectional analysis, WTC-exposure gradients were observed for ear symptoms and hearing loss. This study importantly describes the burden of hearing loss and discomfort in the FDNY cohort and may aid in the planning and allocation of resources for this issue. Future assessment of audiometric outcomes will elaborate on our self-reported results with clinical evidence and examine possible mediating effects acting through chronic olfactory system inflammation and auditory health conditions.

## AUTHORS' CONTRIBUTIONS

RZO and DJP had full access to all of the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis. Concept and Design: RZO, MPW, and DJP. Acquisition, analysis or interpretation of data: All authors. Drafting of the manuscript: HLC. Critical revision of the manuscript for important intellectual content: All authors. Statistical analysis: HLC and YL.

## ACKNOWLEDGEMENT

None.

## FUNDING

This research was supported through the National Institute for Occupational Safety and Health (NIOSH) contract numbers 200-2011-39378, 200-2011-39383, 200-2017-93326, 200-2017-93426; NIOSH had no role in study design; collection, analysis, and/or interpretation of data; writing the report; and the decision to submit the report for publication.

## ETHICS APPROVAL AND INFORMED CONSENT

This work was performed at the Fire Department of the City of New York. The Albert Einstein College of Medicine Institutional Review Board reviewed and approved this study. Data were used from participants who provided written consent.

## DISCLOSURE (AUTHORS)

All authors received support from grants and/or contracts from the National Institute for Occupational Safety and Health.

## DISCLOSURE BY AJIM EDITOR OF RECORD

John Meyer declares that he has no competing or conflicts of interest in the review and publication decision regarding this article.

## DISCLAIMER

The Fire Department of the City of New York had no role in study design; collection, analysis, and/or interpretation of data; writing the report; and the decision to submit the report for publication.

## ORCID

*Hilary L. Colbeth* http://orcid.org/0000-0003-0750-2735
*Mayris P. Webber* http://orcid.org/0000-0002-8322-4573

## REFERENCES

1. Centers for Disease Control and Prevention (CDC). Noise and Hearing Loss Prevention. 2018; https://www.cdc.gov/niosh/topics/noise/default.html Accessed June 1, 2018.
2. Zelaya CE, Lucas JW, Hoffman HJ. Self-reported hearing trouble in adults aged 18 and over: United States, 2014. *NCHS Data Brief*. 2015;1–8. PMID: 26462204.
3. Brackbill RM, Thorpe LE, DiGrande L, et al. Surveillance for World Trade Center disaster health effects among survivors of collapsed and damaged buildings. *MMWR Surveill Summ*. 2006;55:1–18.
4. Stein CR, Lee DJ, Flamme GA, Cone JE. Persistent post-9/11 hearing problems among world trade center health registry rescue and recovery workers, 2001 to 2007. *J Occup Environ Med*. 2017;59:1229–1234.
5. Gabrielson TB, Poese ME, Atchley AA. Acoustic and vibration background noise in the collapsed structure of the World Trade Center. *J Acoust Soc Am*. 2003;113:45–48.
6. Prezant DJ, Weiden M, Banauch GI, et al. Cough and bronchial responsiveness in firefighters at the World Trade Center site. *N Engl J Med*. 2002;347:806–815.
7. Feldman DM, Baron SL, Bernard BP, et al. Symptoms, respirator use, and pulmonary function changes among New York City firefighters responding to the World Trade Center disaster. *Chest*. 2004;125:1256–1264.
8. Lioy PJ, Weisel CP, Millette JR, et al. Characterization of the dust/smoke aerosol that settled east of the World Trade Center (WTC) in lower Manhattan after the collapse of the WTC 11 September 2001. *Environ Health Perspect*. 2002;110:703–714.

9. Hwang YH, Chiang HY, Yen-Jean MC, Wang JD. The association between low levels of lead in blood and occupational noise-induced hearing loss in steel workers. *Sci Total Environ*. 2009;408:43–49.
10. Vyskocil A, Leroux T, Truchon G, et al. Ethyl benzene should be considered ototoxic at occupationally relevant exposure concentrations. *Toxicol Ind Health*. 2008;24:241–246.
11. Campo P, Morata TC, Hong O. Chemical exposure and hearing loss. *Dis Mon*. 2013;59:119–138.
12. Weakley J, Hall CB, Liu X, et al. The effect of World Trade Center exposure on the latency of chronic rhinosinusitis diagnoses in New York City firefighters: 2001-2011. *Occup Environ Med*. 2016;73:280–283.
13. Aldrich TK, Gustave J, Hall CB, et al. Lung function in rescue workers at the World Trade Center after 7 years. *N Engl J Med*. 2010;362:1263–1272.
14. Weakley J, Webber MP, Gustave J, et al. Trends in respiratory diagnoses and symptoms of firefighters exposed to the World Trade Center disaster: 2005-2010. *Prev Med*. 2011;53:364–369.
15. Webber MP, Glaser MS, Weakley J, et al. Physician-diagnosed respiratory conditions and mental health symptoms 7-9 years following the World Trade Center disaster. *Am J Ind Med*. 2011;54:661–671.
16. Le TN, Straatman LV, Lea J, Westerberg B. Current insights in noise-induced hearing loss: a literature review of the underlying mechanism, pathophysiology, asymmetry, and management options. *J Otolaryngol Head Neck Surg*. 2017;46:41.
17. Kujawa SG, Liberman MC. Acceleration of age-related hearing loss by early noise exposure: evidence of a misspent youth. *J Neurosci*. 2006;26:2115–2123.
18. Lewkowski K, Li IW, Fritschi L, Williams W, Heyworth JS. A systematic review of full-shift, noise exposure levels among construction workers: are we improving? *Ann Work Expo Health*. 2018;62:771–782.
19. Boateng CA, Amedofu GK. Industrial noise pollution and its effects on the hearing capabilities of workers: a study from saw mills, printing presses and corn mills. *Afr J Health Sci*. 2004;11:55–60.
20. Kujawa SG, Liberman MC. Adding insult to injury: cochlear nerve degeneration after "temporary" noise-induced hearing loss. *J Neurosci*. 2009;29:14077–14085.
21. Liberman MC, Epstein MJ, Cleveland SS, Wang H, Maison SF. Toward a differential diagnosis of hidden hearing loss in humans. *PLoS ONE*. 2016;11:e0162726.
22. Moser T, Starr A. Auditory neuropathy-neural and synaptic mechanisms. *Nat Rev Neurol*. 2016;12:135–149.
23. Basner M, Babisch W, Davis A, et al. Auditory and non-auditory effects of noise on health. *Lancet*. 2014;383:1325–1332.
24. Lin FR, Yaffe K, Xia J, et al. Hearing loss and cognitive decline in older adults. *JAMA Int Med*. 2013;173:293–299.
25. Bhatt JM, Bhattacharyya N, Lin HW. Relationships between tinnitus and the prevalence of anxiety and depression. *Laryngoscope*. 2017;127:466–469.
26. Groschel M, Basta D, Ernst A, Mazurek B, Szczepek AJ. Acute noise exposure is associated with intrinsic apoptosis in murine central auditory pathway. *Front Neurosci*. 2018;12:312.

**How to cite this article:** Colbeth HL, Zeig-Owens R, Liu Y, et al. Persistent self-reported ear and hearing problems among World Trade Center-exposed firefighters and emergency medical service workers, 2001-2017—A longitudinal cohort analysis. *Am J Ind Med*. 2019;62:43–49. https://doi.org/10.1002/ajim.22925